Roberto de Andrade Martins*

Romagnosi and Volta's Pile: Early Difficulties in the Interpretation of Voltaic Electricity

1. Who Discovered Electromagnetism?

Most of us have learnt that Hans Christian Ørsted discovered electromagnetism in 1820.[1] However, according to the 15th edition of the *Encyclopaedia Britannica*, the discovery of electromagnetism was not due to Ørsted: it was made by Romagnosi, an Italian jurist, who reported his discovery in an obscure newspaper in 1802. Under "Magnetism", we read:

> The origin of magnetic properties remained a mystery, but a major step forward occurred in 1820, when a Danish physicist, Hans Christian Ørsted, observed that an electric current flowing in a wire affected a nearby magnet. (The same discovery had been made and reported by Gian Domenico Romagnosi, an Italian jurist, in *Gazetta di Trentino* [*sic*], 3rd August, 1802, but was ignored).[2]

Similarly, under "Electromagnetic Radiation": "The magnetic effect of a current had been observed earlier (1802) by an Italian jurist, Gian Domenico Romagnosi, but the announcement was published in an obscure newspaper".[3]

In the *Micropaedia* section of the same edition of the *Encyclopaedia Britannica* we read again: "This phenomenon had been first discovered by the Italian jurist Gian Domenico Romagnosi in 1802, but his announcement was ignored".[4]

*The author is grateful to the Brazilian National Council for Scientific and Technological Development (CNPq) for financial support for this research.

[1] ØRSTED (1820). Ørsted's paper was reproduced in ØRSTED (1820a). It was reprinted in ØRSTED (1920a). This book also contains facsimile reprints of early translations (German, French, English, Italian) of Ørsted's work.

[2] BLEANEY (1980), p. 311.

[3] PHILLIPS (1980), p. 647.

[4] "Ørsted, Hans Christian", *Encyclopaedia Britannica* (15th ed.), Chicago: Encyclopaedia Britannica, 1980, *Micropaedia*, VII, p. 596.

Analogous claims can be found in other publications:

> Romagnosi, in 1802, had observed the deflection of a magnetic needle in the presence of a conductor carrying an electric current, but he seemed to have attached no importance to his discovery at the time, and certainly no results came of it. Romagnosi himself made no claims to priority in the discovery of electromagnetism.[5]

In a note by the Commission responsible for the publication of Volta's correspondence, we read:

> The phenomenon observed by Romagnosi was not duly taken into consideration at that time, until the Danish Christian Ørsted, professor of physics at the University of Copenhagen, in his Latin monograph called "Experimenta circum effectum conflictus electrici in acum magneticum", published in Copenhagen on July 21, 1820 (and presented by de La Rive to the French Academy on September 11 of the same year) clearly brought to light the action of the electric current upon a magnetic needle.[6]

Those claims are not new. Soon after the publication of Hans Christian Ørsted's discovery (1820), he was accused of plagiarism. In 1820, Pietro Configliachi, editor of the *Giornale di fisica, chimica, storia naturale, medicina ed arti*, called the attention of the public, for the first time, to the precedence of Romagnosi over Ørsted:

> The jurist Prof. Romagnosi recognised that a magnetic needle had a deflection different from other [needles] when it was submitted for some time to the electric current of a pile; and the brave chemist Mojon of Genoa tried to magnetise sewing needles that were put in the electric circuit of a similar apparatus for about twenty days.[7]

In a footnote, Configliachi added the following information:

> Those reports are registered in P. Aldini's Theoretical and practical essay on Galvanism, printed in Paris in 1804, and in Izarn's Manual of Galvanism, published in the same city in the same year. In 1808 Mr. Romagnosi, who was then my colleague in this University, told me about his discovery and stated that the needle where that extraordinary deflection was observed was not part of the union between the two poles.[8]

Configliachi's account suggests that Mojon and Romagnosi detected different phenomena. According to him, Mojon observed the magnetisation of steel needles that were traversed by an electric current, but Romagnosi observed the effect of an electric current upon a magnetic needle that was not traversed by the current.

Shortly afterwards, a letter from Configliachi was printed in the *Bibliothèque universelle des sciences, belles lettres et arts* of Geneva. The letter itself did not mention Romagnosi, but it was followed by a "Remark of the translator":

[5] MEYER (1971), p. 46.
[6] *VE*, IV, p. 540.
[7] CONFIGLIACHI (1820), p. 449.
[8] *Ibid*., p. 449, footnote 2.

> We take this opportunity to claim for a Genoese chemist (Mr. Mojon) at least the discovery of the influence of voltaism [*voltaïsme*] on the deflection of the needle, if not Orsted's [*sic*] full discovery. This is textually what we read in the *Traité sur le galvanisme* published by Prof. Aldini in Paris in 1804. (Page 191, 4th ed.)
> Mr. Mojon, Prof. of chemistry in Genoa, who is the author of the following procedure, has recently communicated it to me.
> He put very thin sewing needles, two inches long, in a horizontal position, and he established a communication of their two extremities with a cup apparatus with 100 glasses. After twenty days he took out the needles that were a little bit oxidised, but at the same time magnetic, with a clearly discernible polarity. This new property of Galvanism was noticed by other observers, and lately by Mr. Romanesi [*sic*], physicist [*sic*] of Trent, *who recognised that Galvanism deflected the magnetic needle*.[9]

A copy of this comment was sent by Nürnberger to Gilbert, the editor of the *Annalen der Physik*, who published it.[10] Gilbert added a footnote pointing out that the honour of the discovery of electromagnetism could be ascribed either to the one who first chanced to observe it but did not use it, or to him who called the attention of the public to the fact, or to him who investigated it and provided a scientific foundation to it. In other words, the answer to the question "who discovered electromagnetism?" depended on the very concept of "discovery".

In England, Humphry Davy also called the attention to Mojon's and Romagnosi's researches, but denied that the later had anticipated Ørsted:

> Since this letter has been written, D. Marcet has been so good as to send me from Genoa, some pages of Aldini on Galvanism, and of Izarn's Manual of Galvanism, published at Paris more than sixteen years ago. M. Mojon, senior, of Genoa, is quoted in these pages as having rendered a steel needle magnetic, by placing it in a Voltaic circuit for a great length of time. This, however, seems to have been dependent merely upon its place in the magnetic meridian, or upon an accidental curvature of it; but M. Romagnesi [*sic*], of Trent, is stated to have discovered that the battery of Volta caused a declination of the needle; the details are not given, but if the general statement be correct, the author could not have observed the same facts as M. Œrsted, but merely supposed that the needle had its magnetic poles altered after being placed in the Voltaic circuit as a part of the electrical combination.[11]

In which sense could Romagnosi have anticipated Ørsted? What does it mean "to be the discoverer of electromagnetism"? Let us apply Hanson's analysis[12] of "discovery" to this particular case.

The basic electromagnetic phenomenon is this: an electric current affects a magnetic

[9] Anon. [Ridolfi?], in CONFIGLIACHI (1821), pp. 73-4.
[10] NÜRNBERGER (1821).
[11] DAVY (1821), p. 43.
[12] HANSON (1967).

needle. Now, according to Hanson, we may state that P discovered X if and only if:[13]

1) X does really occur,
2) P did really find X,
2') P was the first to find X,
3) P interpreted X correctly.

The "traditional view" ascribes the discovery of electromagnetism to Ørsted in the following sense:

1) it is accepted that an electric current does indeed affect a magnetic needle,
2) it is accepted that Ørsted did really find that an electric current affects a magnetic needle,
2') it is accepted that Ørsted was the first to find that an electric current affects a magnetic needle,
3) it is accepted that Ørsted interpreted correctly his finding (not, of course, in the way it was understood within Maxwell's electromagnetism, but in a phenomenological way).

Authors who claimed that Romagnosi was the discoverer of electromagnetism supposed that he did really find that an electric current affects a magnetic needle, and that he did it many years before Ørsted. Even if one accepted this as a historical fact, it would be possible to challenge Romagnosi's understanding of the phenomenon he observed. But the main historical point is this: did he really observe the action of an electric current upon a magnetic needle? My answer will be "no", and therefore it will not be necessary to discuss other aspects of the priority issue.

2. Gian Domenico Romagnosi

Romagnosi was sometimes described as a physicist, sometimes as a jurist. His name was written in different forms. Those mistakes suggest that most information was second-hand, and Romagnosi was unknown to the scientific community. Who was Romagnosi, after all?

Giovanni Domenico (or Gian Domenico) Gregorio Giuseppe Romagnosi (figure 1) was born on December 11, 1761 in Salso Maggiore, a small village close to Piacenza.[14] At high school, he became highly interested in mathematics, physics and philosophy.[15] He completed his elementary studies in 1781 and started studying law at Parma. He obtained his title in August 1786 and soon became a respected lawyer. In

[13] *Ibid*., p. 330.
[14] For biographical information, see CANTÙ (1861), GIORGI (1841) and GIORGI (1842).
[15] After retiring from his juridical career, many years later, Romagnosi published works on mathematics and logic. See ROMAGNOSI (1822) and his work in GENOVESI (1832).

1791 he published his first book on law, *Genesi del diritto penale*, that underwent three editions during his lifetime. In the same year he became a magistrate at Trent (at that time, the city was dominated by the French) – a position he held for three years. Afterwards, he worked as a lawyer in the same city. In 1799, Austria took Trent. Romagnosi became suspect, because of his former association with the French government. He was arrested and kept captive for 15 months in Innsbruck, being acquitted and released the next year. In 1801, after the French had won the region back from Austria, Romagnosi was elected Secretary of the Higher Council of Trent.

Figure 1 Gian Domenico Romagnosi. From CANTÙ (1861), frontispiece.

While Romagnosi was in prison, the discovery of Volta's pile was made public, and voltaic experiments became a fashion. Gian Domenico managed to begin experiments while he was still in jail, and devoted himself to physical studies for a few years afterwards. This non-professional research ultimately led to his famous experiment on the effect of the pile on a magnetic needle, which was made public through a local newspaper[16] on August 3, 1802. Shortly afterwards he moved to Parma, where he accepted a university chair in public law. Throughout his career, Romagnosi published several books. He also taught law at Pavia and Milan. He died on June 8, 1835, at Corfù.

Between 1804 and 1820 Romagnosi's experiment was forgotten and it was recalled only after Ørsted's discovery. Several interpretations arose: Ørsted could

[16] Different authors refer to that journal as *Gazzetta di Trento*, *Gazzetta di Trentino* or *Gazzetta di Roveredo*, but the notice was published in *Ristretto dei foglietti universali di Trento*.

have discovered electromagnetism independently of Romagnosi, but priority belonged to the Italian researcher; or Ørsted should receive the whole credit for the discovery, because he was the first to investigate it in a detailed way and to call the attention of other scientists to the phenomenon. Some authors suggested that perhaps Ørsted knew of Romagnosi's experiment – in that case, he would be guilty of plagiarism, because he did not refer to Romagnosi's early findings.

It was even claimed that Ørsted had read Aldini's book and was aware of Romagnosi's experiment. It is known that Ørsted was in Paris in 1802-1803, and there he met Aldini.[17] If Aldini had already learned about Romagnosi's experiment, Ørsted could have heard about it at that time. Aldini's book was published only in 1804, when Ørsted had already returned to Denmark, but it is likely that they kept in contact, because Aldini referred in his book to information he had just received from Ørsted.[18] Aldini's book was well known in the early 19th century, and Ørsted was certainly aware of it. Indeed, his friend Ritter cited Aldini's book in a letter he sent to Ørsted in 1804.[19] It is likely that Ørsted read Aldini's book, but we do not know whether Ørsted paid attention to the account of Romagnosi's experiment.

Romagnosi was alive in 1820, and it is likely that he was informed about the priority issue concerning the discovery of electromagnetism, but he never published any claim concerning this subject. It is remarkable that Ørsted did not comment on this priority issue either.

After Romagnosi's death, in 1835, new claims appeared in the press. Cesare Cantù published, in that same year, a biography where we find:

> He [Romagnosi] was also in love with physics, and finding it renewed after Volta's discovery, repeated the experiments, and wrote to Bramieri: "I have prepared a new theory of zodiacal light. I have lately published, in the *Gazzetta di Rovereto*, a discovery of mine on galvanism applied to the magnetism of a magnet". He referred to an experiment (1802) for which others and we attribute to him, with Oerstedt [*sic*], Ampère and Faraday, the disclosure of the great synthesis of electromagnetism: a very indulgent claim.[20]

Up to this time, all references to Romagnosi's experiment had relied upon Aldini and Izarn's accounts. It was in Cantù's book that a reproduction of Romagnosi's obscure paper appeared for the first time. Alessandro Giorgi did the same in the short biography of Romagnosi published at the head of his collected works.[21]

Among physicists, the priest Francesco Zantedeschi was the main supporter of Romagnosi's priority over Ørsted. According to Zantedeschi, if Romagnosi's experiment had been adequately studied when it was published, "it could have been

[17] HAMEL (1860), column 117.
[18] ALDINI (1804), I, p. 376.
[19] Letter from Ritter to Ørsted, August 4, 1804, in ØRSTED (1920), II, pp. 69-89, on p. 88.
[20] CANTÙ (1861), p. 6.
[21] GIORGI (1841), pp. VI-VII; GIORGI (1842), pp. XIII-XIV.

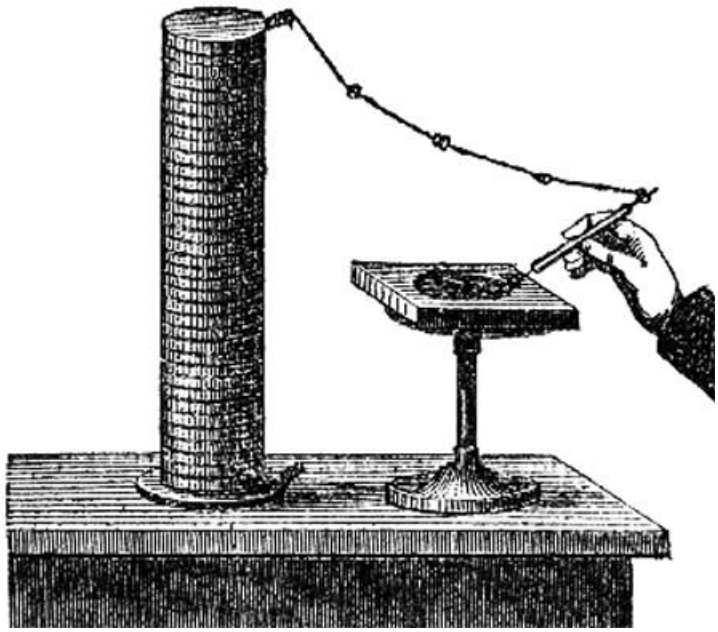

Figure 2 This figure, published by Govi in 1869, is a reconstruction of the compass experiment described by Romagnosi in 1802. From GOVI (1869), p. 432.

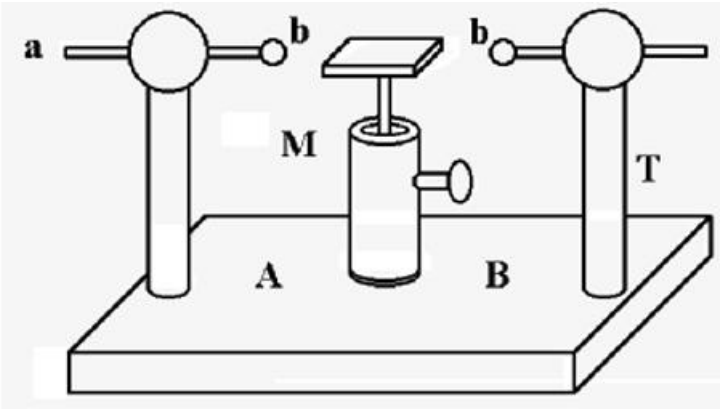

Figure 3 The apparatus described by Izarn in 1804. Author's reconstruction of IZARN (1804), fig. 53, plate III, facing p. 130.

the source of all modern electromagnetic discoveries".[22] One year later, the same author stated that "The electro-magnetic kind of conflict is doubtless due to Italy. Romagnosi and Mojon preceded Oersted by more than fifteen years".[23]

From that time onwards, most Italian authors claimed that Romagnosi was the discoverer of electromagnetism. However, an anonymous[24] review of Zantedeschi's book, published in the *Biblioteca italiana*, criticised those claims, reproduced and analysed Romagnosi's account and interpreted those observations as completely distinct from the discovery of electromagnetism.[25]

3. Romagnosi's Experiment

Romagnosi's original account, entitled "Articolo sul galvanismo", was printed in the *Ristretto dei foglietti universali di Trento*, on August 3, 1802.[26] What was the content (figure 2) of Romagnosi's experiment? This is a complete translation of the article:

> Councillor Mr. Giandomenico Romagnosi, a dweller in this city who is known to the literary republic for other profound productions of his, makes haste to communicate to the European physicists an experiment concerning the galvanic fluid applied to magnetism.
> Mr. Volta's pile was prepared, built of round pieces of zinc and copper, alternating with pieces of humid flannel with water impregnated with ammoniac salt; a silver wire, divided in several pieces like a chain, was attached to the pile. The last segment of the chain passed through a glass tube, and from its exterior termination there stretched a pure silver knob attached to the chain.[27]
> After this was done, he took an ordinary magnetic needle, in the form of a nautical compass, boxed in a square wood plank; and lifting up the crystal that enclosed it, he put it over a glass insulator, near the aforementioned pile.[28]
> Then, taking the silver chain and holding it by the above-mentioned glass tube, he applied its

[22] ZANTEDESCHI (1839), p. 14.
[23] ZANTEDESCHI (1840), p. 9.
[24] The review was published anonymously. Cantù identified the author as Giuseppe Belli. See CANTÙ (1861), p. 6.
[25] ANON. (1840), pp. 60-3.
[26] The following quotations are taken from the version of the article appeared in GIORGI (1841).
[27] According to this account, Romagnosi did not use a metal chain of the kind that was usually employed in electrical experiments, but built a special type of conductor, made of longer pieces of silver attached to each other. Only one end of this chain was connected to the pile, and therefore there was no electric current passing through it. The use of a glass tube suggests that Romagnosi was taking care not to interfere with the electric charge transmitted by the pile to the silver chain. We can infer that Romagnosi was looking for an electric [static] effect.
[28] The use of a glass insulator under the compass is more evidence that Romagnosi was looking for electric effects, because magnetic effects could not depend on insulation. In electromagnetic experiments such as Ørsted's, as pointed out by GOVI (1869), it is irrelevant whether the magnetic needle is in communication with the ground or not.

end or knob to the magnetic needle; and keeping the contact for a few seconds, he made the needle deflect from the direction of the poles by a few degrees. Taking off the silver chain, the needle remained steady in the divergent direction that was given to it. He again applied the same chain, and made the needle diverge even more from the polar direction, and the needle always remained in the same place in which it was left, in such a way that the polarity remained completely damped.[29] In order to verify this result again, he approached the magnetic needle, as close as possible (without touching it, however), now with a piece of watch spring, then with other iron instruments, which beforehand produced a strong attraction upon the same needle even from a distance four times larger; but when it was under the effect of galvanism, they were unable to move it even a hair's breath.[30]

This is what Mr. Romagnosi did afterwards, to restore the polarity. Between the thumb and forefinger of both hands he pressed the ends of the small isolated wood box, without shaking it, and kept it this way for some seconds. The magnetic needle was seen then to move slowly and regain its polarity, not at once but through successive pulsations, like the hand of a watch[31] designed to measure seconds.[32]

This experiment was performed in the month of May and was repeated in the presence of witnesses. In those circumstances he also obtained, without difficulty, an electric attraction at a noticeable distance. He made use of a thin thread soaked in water with ammoniac salt, and attached it to a glass pen. Then he approached the above mentioned silver chain to the thread, at a distance of about one line [1/12 inch], and observed that the thread twisted and flew to join the chain knob, always keeping attached to it as in electric experiments.[33]

Mr. Romagnosi thinks that it is his duty to publish this experiment that will be joined to other ones in a memoir that he is composing on galvanism and electricity. He reserves for that work the account of an atmospheric phenomenon that happens every year in a place of Tyrol close to Prenner, strongly affecting its whole population and submitting it to all the effects of galvanism.

[29] The original text reads: "Di nuovo applicò la medesima catena, facendo divergere vieppiù il detto ago dalla direzione polare, ed ottenne sempre che l'ago rimanesse nel luogo in cui lo aveva lasciato; di modo che la polarità rimaneva interamente ammortizzata". It is very difficult to understand the phenomenon described. Did the needle move from its initial position because of an electric repulsion? That is Govi's interpretation (GOVI (1869), p. 432). The description, however, is not sufficiently clear to allow us to decide for or against that interpretation. Repulsion could not, of course, explain why the needle did not return to its initial position. Govi conjectured that its immobility was due to friction. Perhaps there was a strong attraction between the needle and the wood box that "froze" it in a particular direction.

[30] This is again difficult to understand. Govi interpreted it as evidence that there was a strong friction keeping the needle at rest.

[31] "... a somiglianza d'una sfera da orologio, destinata a segnare i minuti secondi". A literal translation would render this sentence as "similar to the sphere of a watch ..." but that makes no sense.

[32] This is further evidence that Romagnosi was looking for an electric [static] effect. If the needle was kept in its direction by an electrostatic force, it would move when the charge was dissipated – and that would be the effect of holding the box with the hands.

[33] This second experiment, without a magnetic needle, clearly shows that Romagnosi was just trying to observe electric attraction produced by the voltaic pile.

This is the original account of Romagnosi's experiments.[34] It seems that Romagnosi was trying to observe electrostatic[35] effects due to the electric pile. Why should he have attempted to do this? The scientific context around the discovery of Volta's pile helps us to understand his aim.

4. Galvanism and Electricity in the Early Nineteenth Century

Before the development of the pile, as discussed in the first issue of *Nuova Voltiana*,[36] Galvani and Volta had different interpretations of the so-called galvanic phenomena. Galvani believed that those effects were due to a new kind of agent ("animal electricity"), qualitatively different from electricity produced by friction. Volta, who claimed that all galvanic effects were due to electricity, challenged this view.[37]

Using a single metallic pair, it was possible to produce several physiological effects, but nothing similar to electric attraction or repulsion could be directly observed. However, using his "condensatore",[38] Volta was able to increase the electric [static] effect of small charges, and in this way he was able to exhibit the influence of a single metallic pair upon a delicate electrometer. It was necessary to multiply 60 times the "tension" produced by a zinc-silver pair to produce a deflection of 1° of his straw electrometer.[39] His experiments were not convincing, however, because the effect was indirect and the working of the condensing device itself was not easily understood. Some authors who tried to repeat those experiments obtained different results.[40]

Volta's pile was born as a result of his attempt to produce stronger direct electrical effects from galvanic pairs. After several failures, Volta learned how to

[34] According to Romagnosi, the published account was written by one of his friends, Abbot Tamanini, who had witnessed the experiments. See *VE*, IV, p. 540.

[35] The distinction between electrostatic and electrodynamic effects did not exist in 1800, of course. What we nowadays call "electrostatic" was called "electric", but this word was also applied to lightning and other phenomena, in the late 18th century. In this paper, to stress the distinction between electrostatic effects and other electric effects, I shall refer to [static] electricity.

[36] BERNARDI (2000).

[37] There were other debated questions, see KIPNIS (1987) and his essay in this volume; KRAGH (2000), such as the cause of the effects – chemical reaction, or mere contact between two different metals? These issues will not be dealt with here. In the discussion of Volta's hypothesis of metallic electricity, it is possible to stress "metallic" or "electricity". This paper only addresses the difficulty of establishing that the pile does generate electricity.

[38] VOLTA (1782). Notice that this device was invented *before* Galvani's discovery, see HEILBRON (1979), pp. 453-7.

[39] A deflection of 1° of Volta's straw electrometer was equivalent to about 40 volts, see HEILBRON (1970), p. 78.

[40] KIPNIS (1987), p. 122.

combine metal plates and non-metallic conductors to add the individual effects of those pairs. In this way he was able to produce several phenomena similar to those obtained with Leyden jars: "The most important of these results, which includes most of the others, is the construction of an apparatus that is similar in its effects (i.e. by the shock which it produces on the arms, etc.) to the Leyden bottles, or better still to feebly charged electric batteries".[41]

Mertens has recently claimed that the only aim of Volta's pile was to provide a public demonstration device, to be used by the general public: "The pile was meant to convert these people into witnesses of metallic electricity".[42] According to Mertens, Volta had already presented suitable evidence to convince the experts in 1797. However, the scientific community was not converted to Volta's hypothesis, neither in 1797 nor in 1800: there remained reasonable scientific doubt that the metallic pair (or Volta's pile) did really generate electricity, or that it *only* generated electricity.[43]

The pile was a success, but it could not lead at once to the victory of Volta's interpretation. Most of Volta's first paper on the pile was devoted to the description of physiological effects. However, the main property of friction electricity – the very property that led to the discovery of electricity – was attraction (and repulsion). Did the "fluid" produced by the pile exhibit this property?

In the paper where he described his discovery, Volta reported that he was able to observe the effect of a pile with 20 metallic pairs upon an electrometer, but only with the aid of the condenser.[44] Immediately after Volta's discovery, William Nicholson and Anthony Carlisle built a pile containing 17 elements, and applied it to a gold-leaf electrometer.[45] They could only observe deflection using a "revolving doubler" – an instrument built by Nicholson on the same principle as the condenser.

So, after 1800, there were still some reasonable doubts concerning the identity of [static] electric phenomena and galvanic or voltaic phenomena. According to Van Mons, Fourcroy concluded that the pile produced a fluid different from electricity: "His main point is that the fluid of the pile produces no effect (or almost no effect) upon the most sensitive electrometers, and that the fluid of electrical machines does not produce any of the chemical effects of the galvanic pile".[46]

Using large piles, with 80, 100 or 150 elements, Volta was able to obtain small

[41] VOLTA (1800), p. 403.
[42] MERTENS (1998), p. 311.
[43] KIPNIS (1987).
[44] VOLTA (1800), pp. 406-7.
[45] NICHOLSON (1800).
[46] Van Mons, letter to Volta of July 15, 1801, reproduced in *VE*, IV, 1172, p. 49. The production of observable attraction and repulsion with the pile was not a "crucial" experiment, of course, but was a relevant evidence. I will refer only to this specific property because it is the one directly related to Romagnosi's experiments.

deflections (one or two degrees) on his straw electrometer.[47] The paper Volta presented to the Paris Academy of Sciences in October 1801[48] also addressed the question of the electric nature of galvanism, but again he resorted to the condenser to exhibit the electrical effects of the pile. According to Christian Heinrich Pfaff, however, Volta also used a 60-element pile at Paris, producing a deflection of one degree of his straw electrometer.[49] In this letter, Pfaff also emphasised that Volta had been able to charge a large battery (a compound capacitor of 10 square feet surface) with his pile. On October 10 Volta wrote a letter to de la Métherie, describing those experiments.[50] Volta himself acknowledged that the feeble electrical effects produced by a metallic pair, and enlarged by the condenser, did not satisfy those people who wanted to see large-scale effects (*effets en grand*). He remarked that to obtain a direct perceptible effect using his straw electrometer, it was necessary to use a pile with about 60 silver-zinc pairs, and even in that case, the extremities of the straws moved apart only half a line – that is, about 1 mm.[51]

Other authors, two months earlier, had already obtained observable electric effects using Volta's pile. In the "Thermidor, an 9" (July/August 1801) issue of the *Journal de physique, de chimie et d'histoire naturelle*, Erman addressed this subject:

> It was essential to find safe galvanoscopic and galvanometric observation procedures to ascertain the mechanism of the galvanic pile and to track all the phenomena step by step. This scientific demand was soon felt, but was not satisfied; the early observers could only perceive slight vestiges of divergence of the electrometer balls. The torsion balance, the condenser and even the duplicator were put into use to catch those evanescent, meagre signs, that were therefore too equivocal to provide the theory of the phenomena.[52]

Erman noticed that the main conditions for obtaining regular and measurable effects were the use of a large pile (he employed two interconnected 100 elements devices) and the perfect isolation of the pile. He was able to observe attraction between a conductor linked to the pile and an electroscope ball attached to a 2 feet long, thin silver wire, up to distances of about 2 mm (3/4 to 1 line). When the opposite pole of the pile was connected to the ground, Erman was able to observe attraction at distances up to 3 or 4 lines. When the ball touched the conductor, they cohered together and

[47] Volta, letter to Ambrosius Barth, August 29, 1801, reproduced in *VE*, IV, 1176, pp. 54-6. This letter was published in *Annalen der Physik*, 9 (1801), p. 379.
[48] VOLTA (1801).
[49] Pfaff, letter to the editor of the *Allgemeine Literatur-Zeitung*, October 8, 1801, reproduced in *VE*, IV, 1187a, pp. 65-6. This letter was published in *Allgemeine Literatur-Zeitung*, 1801 (n. 207), p. 489; and *Annalen der Physik*, 9 (1801), pp. 489-93.
[50] VOLTA (1801a). This letter was partly reproduced in *VE*, IV, 1188, pp. 67-8.
[51] VOLTA (1801a), p. 313.
[52] ERMAN (1801), p. 121.

could not be detached when the apparatus was strongly shaken.[53] Using a non-conducting thread instead of the silver wire, there was first an attraction and then a repulsion between the ball and the conductor attached to the pile, after they touched. He could also observe strong effects using a sensitive electroscope: in many cases, the gold leaves even touched the walls of the apparatus.[54]

In the same issue of that journal, Ritter reported an experiment using a pile with 84 zinc-silver pairs. He observed the attraction between two gold leaves connected to the opposite poles of the pile, when their distance was about one line.[55] He could also observe attraction and repulsion in a vessel evacuated by a pneumatic machine.

Soon afterwards, Gautherot described some experiments on electric attraction produced with a voltaic pile:

> Finally I will present my researches on attraction. I attached to the upper end of the pile the extremity of a very thin harpsichord wire, and left the rest of the wire to float in the air. At the other end of the pile I connected another metallic wire, and when I presented its free end to that of the first wire, I perceived a motion of the first towards the second; and when the two wires were able to touch, there was very marked adhesion: they seemed attached by something like a magnetic force, and the force was such that I could move those wires in every direction for a few centimetres.[56]

Notice how similar this experiment is to the last one described by Romagnosi. This and other experiments described by Gautherot exhibited a similarity between electric [static] attraction and the effect produced by Volta's pile. Romagnosi's compass experiment can be interpreted as another demonstration that Volta's pile can affect a compass in the same way as [static] electricity.

Van Marum and Pfaff were soon able to obtain even stronger electric effects. They built a pile with 200 silver-zinc pairs, and tested its effects using a very sensitive instrument (Abraham Bennet's gold-leaf electrometer). They reported that the extremities of the gold leaves attained a distance of 5/8 inch.[57]

Of course, to establish that two phenomena have one property in common does not prove that they are of the same nature. Even after there was sufficient evidence that the pile gave rise to attraction and repulsion, as electricity produced by friction does, there remained doubts that the pile produced *only* electricity. Vassalli acknowledged that such experiments "left no doubt that the galvanic apparatus produces electricity".[58] However, he stressed that the pile produced strong muscular

[53] *Ibid*., p. 124.
[54] *Ibid*., p. 125.
[55] RITTER (1801), p. 152.
[56] GAUTHEROT (1801), p. 209.
[57] Van Marum, letter to Volta, November 29, 1801, reproduced in *VE*, IV, 1210, pp. 97-114. This letter was published in *Annales de chimie*, 40 (1801), pp. 289-334.
[58] VASSALLI-EANDI (1804), p. 154.

contractions, but weak electric effects, while the converse was the case for frictional electricity. For that reason, he maintained that the pile produced *two different fluids*: electricity, and a new fluid, that was the cause of muscular contractions and that was produced by chemical reactions in the pile.[59]

In 1805, towards the end of his academic career, Volta wrote his most complete attempt to prove the identity between the electric and galvanic fluids.[60] He submitted this work to a prize competition, as if it had been written by one of his students.[61] Pietro Configliachi published the work only in 1814.

In his 1805 work Volta reported that Humboldt, Tiberio Cavallo, Vassalli, Aldini and de Luc still did not accept that the effects produced by the pile were due to electricity.[62]

Volta had presented most arguments and experiments described in this work in former publications. Concerning electrical repulsion, Volta once more stated that his early experiments showing the effect of a single metallic pair upon an electrometer, using his condenser, were decisive.[63] He admitted that he did not convince everyone, and that for that reason he attempted to produce stronger effects – and here the pile comes in. As described above, in his published 1801 report Volta had used a pile with 60 silver-zinc pairs to produce stronger effects. Now, he reported that he had built a pile with 150 silver-zinc pairs. With that device he was able to produce a 2.5 degree deflection on his straw electrometer[64] – slightly more than 2-mm separation between the straw ends. This was the largest effect that he ever reported. Volta commented that to produce a really big direct effect on his electrometer – a deflection attaining 35 degrees – it would be necessary to have a pile with about 1800-2000 pairs of cooper-zinc elements.[65]

Volta's 1805 memoir tried to present convincing evidence that the pile did produce electricity, by a series of different arguments. At that time, he regarded as decisive the experiment of charging large electric batteries with a pile in a very short time, and showing that in those cases both devices acquired the same electric tension, as measured by an electrometer.[66] Volta also presented a detailed analysis and explanation of the differences between piles and Leyden jars (or batteries) concerning physiological effects. As in earlier papers, the observation of [static] electrical effects was only part of the argument for the

[59] *Ibid*., p. 155.
[60] VOLTA (1805).
[61] HEILBRON (1970), p. 80. Everywhere, in that work, Volta is referred to in the third person: "il nostro Volta Professore di Fisica Sperimentale nell'Università di Pavia e venerato mio Maestro" (VOLTA (1805), p. 2).
[62] VOLTA (1805), pp. 10-2, 14.
[63] *Ibid*., pp. 19-20.
[64] *Ibid*., p. 33.
[65] *Ibid*., p. 61.
[66] *Ibid*., p. 31.

production of electricity by the pile, but it was a central one.

To sum this section up, we have seen that soon after the discovery of Volta's pile several researchers (including Volta himself) tried to produce with its aid several phenomena that had been observed with electricity produced by friction. I claim – as a few authors in the 19th century (especially Belli and Govi) already did – that the aim of Romagnosi's experiments was also to try whether the pile was able to produce [static] electrical attraction. The use of a magnetic needle was only incidental. As Romagnosi did not close his electrical circuit, he never observed the effect of a magnetic current upon the magnetic needle.

5. Izarn and Aldini's Accounts

If we compare Romagnosi's experiments to Ørsted's, we observe profound differences. Ørsted was careful to avoid electric [static] forces in his experiments, and described that the electric current produced an effect upon the magnetic needle even when there was a metallic shield between the wire and the compass. Besides, Ørsted also tried non-magnetic needles and noticed that the electric current did not affect them.

How could Romagnosi's experiments be described as equivalent to Ørsted's? The main reason was that most authors relied upon Aldini's and Izarn's accounts. Let us return to those works.

Joseph Izarn published in 1804 his *Manuel du galvanisme*. He was an expert on galvanism, and presented lectures on this subject before the *Société libre des sciences, lettres et arts de Paris*, the *Société académique des sciences* and the *Société galvanique*. Scientists, politicians and other eminent people (such as Laplace, Lacépède, Chaptal, Joseph and Lucien Bonaparte) attended his demonstrations.

Izarn's account of Romagnosi's experiment appeared in a section called: "Apparatus to recognise the action of Galvanism on the polarity of a magnetic needle".[67] According to Izarn, in this experiment a needle was submitted to a galvanic current that passed through it (figure 3):

> *Preparation*. Adapt the horizontal wires **ab**, **bd** of the apparatus[68] in such a way that their two bobs [**bb**] have a distance slightly smaller that the length of the needles you want to submit to the experiment; and, at the place of the bobs **bb**, [...] adapt to the wires either a small clip or a small plate.
> *Usage*. After placing the needle in such a way that its two extremities are held by the two small clips; connect **d** with one of the ends of an Electro-motor,[69] and **a** with the other end.

[67] IZARN (1804), p. 120.
[68] *Ibid*., fig. 53, plate III, facing p. 130.
[69] In 1800 Volta had proposed the name "electro-motor" [*electromoteur*] for his pile. In the case of Izarn's account, the apparatus was a voltaic pile with about 40 plates.

> *Effects*. According to the observations of Romagnési [*sic*], physicist of Trent, a needle that is already magnetised and that is submitted to a galvanic current in this way suffers a deflection; and, according to those of J. Mojon, wise chemist of Genoa, non-magnetised needles acquire, in this way, a kind of magnetic polarity.[70]

According to this description, the electric current passed through the magnetic needle, and the experiment was not equivalent to Ørsted's. In the situation described by Izarn, the electric current should produce no force upon the magnetic needle.

Let us now turn to Aldini's account, presented in his book *Essai théorique et expérimental sur le galvanisme.*[71] The relevant quotation can be found in a chapter where Aldini discussed the relation between electricity and magnetism. Aldini recalled that Aepinus, Van Swinden, Cavallo and Coulomb had already pointed out that thunderbolts could change the polarity of magnetic needles.[72] For that reason, Aldini tried to find out whether steel needles could be magnetised by putting them inside a hollow pile. He only obtained very weak effects and was unable to conclude anything. He noticed, however, a magnetisation of needles that were traversed for a long time by the current produced by a strong pile.[73] After describing his attempts, Aldini refers to experiments made by Mojon and Romagnosi:

> Here is another procedure that is, in my opinion, simpler and easier. Its author, Mr. Mojon, has recently communicated it to me.
> He put very thin sewing needles, two inches long, in a horizontal position, and then connected their two ends to the two poles of a cup apparatus with a hundred glasses; after twenty days he took out the needles that were somewhat oxidised, but at the same time magnetised, with a clearly noticeable polarity. This new property of galvanism was noticed by other observers, and lately by Mr. Romanesi [*sic*], physicist of Trent, who recognised that galvanism deflected the magnetised needle.[74]

Did Aldini have first-hand information about Romagnosi? Although Aldini was Italian, it is unlikely that he knew Romagnosi, otherwise he would not have made a mistake about his name and profession.

Notice that both Izarn and Aldini described experiments involving electric currents. Those who only read those short accounts could interpret Romagnosi's experiment as being similar to Ørsted's.

[70] IZARN (1804), p. 120.
[71] There is a former book published by Aldini where Romagnosi's experiment was not cited: ALDINI (1803).
[72] ALDINI (1804), I, p. 190.
[73] *Ibid*., p. 191.
[74] *Ibid*.

6. Electric Attraction

From our privileged standpoint, it is easy to interpret Romagnosi's effects as due to electrostatic forces. Is this just an anachronistic "Whig" interpretation of the situation in the early 19th century? Could a physicist in 1802 understand Romagnosi's experiment in the same way as we do? Let us review some other relevant experiments.

An effect similar to that observed by Romagnosi had already been described for [static] electricity several decades before. An anonymous correspondent of the Royal Society reported in 1746 that the magnetic needle of a compass was strongly affected when he wiped its cover glass with his finger to clean it from dust. He then did some experiments and described the phenomenon:

> The same Glass being rubb'd a very little more with a Finger, a Bit of Muslin, or of Paper, would attract either End of the Needle, so as to hold it to the Glass, for several Minutes, far out of the due Direction, according to what part of the Glass was most excited.
> And when the Needle has for some time adhered to the Glass, and afterwards dropt loose, and made Vibrations, those Vibrations would not be bisected, as usual, by that Point where the Needle should rest, but either be made all on one Side, or be very unequally divided, by means of some Remains of electrical virtue in that Part of the Glass which had attracted the Needle; until at length, after fifteen Minutes or more, all the Electricity being evaporated, the magnetical Power took place.[75]

Nowadays we know that electric effects produced by friction usually involve small amounts of electric charge but high potentials, while the pile produces a steady current involving a large charge but at a low tension. Could an effect similar to those described above be produced by a voltaic pile? If the pile could produce only a very slight effect upon a straw electrometer, how could it produce an observable effect upon a magnetic needle?

It is not necessary to repeat Romagnosi's experiment to check whether it is possible to explain it by [static] electrical forces. Bouvier reported an experiment similar to that of Romagnosi, in 1803. He performed several experiments using a voltaic pile and observed attraction effects:

> Exp. 5. On a pile of 140 series of zinc, silver, and pasteboard, impregnated with a solution of salt, I placed an iron pivot, and on this pivot a very delicate and sensitive compass needle. The friction was almost nothing. I first applied one hand to the base of the pile, and I carried the other [hand] near to the needle. I observed a slow and oscillating approach [...].[76]

The attraction was also observed when he used non-magnetic needles. Similar

[75] ANON. (1746), pp. 243-4.
[76] BOUVIER (1804), p. 304. This article was first published in the so-called "Journal de Van Mons" [*Journal de chimie*, 11 (1803), p. 52] and was translated and published in Nicholson's Journal and in "Gilbert's Annalen" [*Annalen der Physik*, 4 (1804), p. 434].

effects were described when, instead of his hands, Bouvier used a metallic conductor linked to the lower end of the pile, and approached it to the needle.

It is relevant to point out that in 1805 (the year following the publication of Aldini's and Izarn's books), Carlo Amoretti, the editor of the *Nuova scelta d'opuscoli interessanti*, compared Bouvier's experiment to Romagnosi's:

> The action of galvanism upon a magnetic needle was first known in Italy, before other places. Mr. Romagnosi, a professor of Civil Law at Parma and an ingenuous dilettante physicist, in the year 1802, touched the needle of a compass with a silver wire attached to a voltaic pile, and produced a deflection of several degrees from its pole, to which it did not return [...]. See the *Gazzeta di Roveredo* for 1802, number 65. Afterwards, in 1803, Mr. Bouvier observed that the voltaic pile attracted a magnetic needle and also a non-magnetic brass needle [...].[77]

In the early 19th century, therefore, several experiments (some of them similar to those reported by Romagnosi) exhibited a strong similarity between the effects produced by [static] electricity and by Volta's pile. They could be interpreted as evidence for the identity of the two classes of phenomena. After the discovery of electromagnetism by Ørsted, it took a long time before Romagnosi's experiment was analysed and shown to involve merely electrostatic attraction.

In his review of Zantedeschi's book and detailed discussion of Romagnosi's experiment, Belli denied that the jurist could observe any effect due to an electric current. Only one of the poles of the voltaic pile was connected to the silver chain, and the magnetic needle was kept over a glass insulator. Therefore, only a very small charge could have passed through the silver chain when it touched the needle. The reviewer pointed out that even the much stronger discharge of a Leyden bottle could not move a magnetic needle.[78] The same reviewer suggested that the phenomenon observed by Romagnosi and the apparent insensibility of the magnetic needle when iron pieces were brought close to it could be due to friction, and that, when Romagnosi held the wood block between his fingers, he shook it and this broke its immobility.

However, we do not estimate that Romagnosi's observations were deprived of merit, especially at that time; they could provide – specially the one on the attraction of the wet thread – a suitable way of exhibiting the identity between the properties of the so-called galvanic fluid and those of the electric fluid.[79]

Indeed, we may conclude that Romagnosi's discovery was relevant, since it was not altogether clear that voltaic and electrical phenomena were essentially identical. Had Romagnosi's work been correctly described, it could have contributed towards the early interpretation of voltaic effects.

[77] AMORETTI (1805).
[78] ANON. (1840), p. 62.
[79] *Ibid.*, p. 63.

BIBLIOGRAPHY

ALDINI, JEAN (1804), *Essai théorique et expérimental sur le galvanisme, avec une série d'expériences faites en présence des commissaires de l'Institut National de France et en divers amphithéâtres anatomiques de Londres*, Paris: Imprimerie de Fournier Fils, an XII [1804], 2 vols.

ALDINI, JOHN (1803), *An Account of the Late Improvements in Galvanism, with a Series of Curious and Interesting Experiments performed before the Commissioners of the French National Institute and repeated lately in the Anatomical Theatres of London*, London: Cuthell and Martin, 1803.

AMORETTI, CARLO (1805), "Nota", *Nuova scelta d'opuscoli interessanti sulle scienze e sulle arti*, 1 (1805), p. 202.

ANON. (1746), "A Letter to Mr. Benj. Robins, F.R.S. shewing that the Electricity of Glass Disturbs the Mariners [*sic*] Compass, and also Nice Balances", *Philosophical Transactions*, 44 (1746), pp. 242-5.

ANON. (1840) [Belli, Giuseppe?], "Saggi dell'elettro-magnetico e magneto-elettrico di Francesco Zantedeschi", *Biblioteca italiana*, 98 (1840), pp. 48-63.

BLEANEY, BREBIS (1980), "Magnetism", in *Encyclopaedia Britannica*, (15th ed.), Chicago: Encyclopaedia Britannica, 1980, *Macropaedia*, XI, pp. 309-28.

BERNARDI, WALTER (2000), "The Controversy on Animal Electricity in Eighteenth-Century Italy: Galvani, Volta and Others", in BEVILACQUA, FABIO and FREGONESE, LUCIO eds., *Nuova Voltiana: Studies on Volta and his Times*, Milano: Editore Ulrico Hoepli, 2000, I, pp. 101-14.

BOUVIER, S.P. (1804), "Galvanic Experiments with Ice, and a Method of rendering the Electric Attraction of the Pile very Evident", *Journal of Natural Philosophy, Chemistry and the Arts*, 7 (1804), pp. 303-5.

CANTÙ, CESARE (1861), *Gian Domenico Romagnosi*, Torino: Unione Tipografico-Editrice (Galleria Nazionale del Secolo XIX. I Contemporanei Italiani, 17), 1861.

CONFIGLIACHI, PIETRO (1820), "Relazione delle ricerche intraprese alla Scuola di Fisica dell'I.R. Università intorno alla reciproca azione elettrica e magnetica", *Giornale di fisica, chimica, storia naturale, medicina ed arti*, [decade II] 3 (1820), pp. 447-50.

CONFIGLIACHI, PIETRO (1821), "Lettre du prof. Configliachi au Marquis Ridolfi sur les expériences voltaïco-magnétiques; communiquée au Prof. Pictet", *Bibliothèque universelle des sciences, belles lettres et arts* [Genève], 16 (1821), pp. 72-4.

DAVY, HUMPHRY (1821), "On the Magnetic Phænomena produced by Electricity; in a Letter from H. Davy, Bart. F.R.S. to W.H. Wollaston, M.D. P.R.S", *Philosophical Magazine and Journal of Natural Philosophy*, 58 (1821), pp. 43-50.

DE GIORGI, ALESSANDRO (1841), "Cenni sulla vita di Giandomenico Romagnosi", in ROMAGNOSI, GIOVANNI DOMENICO (1841-52), I, pp.V-XIII.

ID. (1842), "Cenni sulla vita di G.D. Romagnosi", in ROMAGNOSI, GIOVANNI DOMENICO (1842), pp. V-XV.

ERMAN, PAUL (1801), "Sur les phénomènes électrométriques de la colonne de Volta", *Journal de physique, de chimie, d'histoire naturelle et des arts*, 53 an IX [1801], pp. 121-34.

GAUTHEROT, N. (1801), "Mémoire sur le galvanisme", *Annales de chimie ou recueil des mémoires concernant la chimie et les arts qui en dependant*, 39 an IX, [1801], pp. 203-10.

GENOVESI, ANTONIO (1832), *La Logica per i giovanetti ...: Con vedute fondamentali sull'arte logica di Giandomenico Romagnosi*, Milano: per Antonio Fontana, 1832.

GOVI, GILBERTO (1869), "Romagnosi e l'elettro-magnetismo", *Atti della Reale accademia delle scienze di Torino*, 4 (1869), pp. 426-39.

HAMEL, J. (1860), "Die Entstehung der galvanischen und electromagnetischen Telegraphie", *Bulletin de l'Académie Impériale des Sciences de St.-Pétersbourg*, 2 (1860), columns 97-136.

HANSON, NORWOOD RUSSELL (1967), "An Anatomy of Discovery", *The Journal of Philosophy*, 64 (1967), pp. 321-52.

HEILBRON, JOHN L. (1970), "Volta, Alessandro Giuseppe Antonio Anastasio", in GILLISPIE, CHARLTON COUSLTON ed., *Dictionary of Scientific Biography*, New York: Charles Scribners Sons, 1970, XIV, pp. 69-82.

ID. (1979), *Electricity in the 17th and 18th Centuries: A Study of Early Modern Physics*, Berkeley: University of California Press, 1979.

IZARN, JOSEPH (1804), *Manuel du galvanisme, ou description et usage des divers appareils galvaniques employés jusqu'à ce jour, tant pour les recherches physiques et chimiques, que pour les applications médicales*, Paris: J.F.-Barrau, Dumotiez, an XII, 1804.

KIPNIS, NAHUM (1987), "Luigi Galvani and the Debate on Animal Electricity, 1791-1800", *Annals of Science*, 44 (1987), pp. 107-42.

KRAGH, HELGE (2000), "Confusion and Controversy: Nineteenth-Century Theories of the Voltaic Pile", in BEVILACQUA, FABIO and FREGONESE, LUCIO eds., *Nuova Voltiana: Studies on Volta and his Times*, Milano: Editore Ulrico Hoepli, 2000, I, pp. 133-57.

MERTENS, JOOST (1998), "Shocks and Sparks: The Voltaic Pile as a Demonstration Device", *Isis*, 89:2 (1998), pp. 300-11.

MEYER, HERBERT W. (1971), *A History of Electricity and Magnetism*, Cambridge, MA: Massachusetts Institute of Technology, 1971.

NICHOLSON, WILLIAM (1800), "Account of the New Electrical or Galvanic Apparatus of Sig. Alex. Volta, and Experiments Performed with the Same", *Journal of Natural Philosophy, Chemistry, and the Arts*, 4 (1800), pp. 179-87.

NÜRNBERGER (1821), "Von Hrn Postmeister Dr. Nürnberger", *Annalen der Physik*, 68 (1821), p. 208.

ØRSTED, HANS CHRISTIAN (1820), *Experimenta circum effectum conflictus electrici in acum magneticum*, Hafniae: Schultz, 1820.

ID. (1820a), "Experimenta circum effectum conflictus electrici in acum magneticum", *Journal für Chemie und Physik*, 29 (1820), pp. 275-81.

ID. (1920), *Correspondance de H.C. Örsted avec divers savants*, HARDING, M.C. ed., Copenhagen: H. Aschehoug, 1920, 2 vols.

ID. (1920a), *The Discovery of Electromagnetism made in the Year 1820 by H.C. Oersted*, LARSEN, ABSALON ed., Copenhagen: [s.n.], 1920.

PHILLIPS, MELBA (1980), "Electromagnetic Radiation", in *Encyclopaedia Britannica*, (15th ed.), Chicago: Encyclopaedia Britannica, 1980, *Macropaedia*, VI, pp. 644-65.

RITTER, JOHANN WILHELM (1801), "Notice des phénomènes d'attraction et de répulsion, dépendant de la pile galvanique", *Journal de physique, de chimie, d'histoire naturelle et des arts*, 53 an IX [1801], pp. 152-5.

ROMAGNOSI, GIOVANNI DOMENICO (1802), "Articolo sul galvanismo", *Ristretto dei foglietti universali di Trento*, 62 (1802).

ID. (1822), *Dell'insegnamento primitivo delle matematiche*, Milano: G. Pirotta, 1822.

ID. (1841-52), *Opere di Giovanni Domenico Romagnosi*, GIORGI, ALESSANDRO DE ed., Palermo: Frasconia-Bambera, Clamis e Roberti, 1841-52, 8 vols.

ID. (1842), *Opere filosofiche edite ed inedite di G.D. Romagnosi*, GIORGI, ALESSANDRO DE ed., Milano: Perelli e Mariani, 1842.

VASSALLI-EANDI, ANTOINE-MARIE (1804), "Expériences et observations sur le fluide de l'électro-moteur de Volta", *Mémoires de l'Académie des sciences, littérature et beaux-arts de Turin pour les annés X et XI. Sciences physiques et mathématiques*, 12 (1804), pp. 123-56.

VOLTA, ALESSANDRO (1782), "Del modo di rendere sensibilissima la più debole elettricità sia naturale che artificiale", *Philosophical Transactions*, 72:1 (1782), pp. 237-83.

ID. (1800), "On the Electricity excited by the mere Contact of conducting Substances of different Kinds" [in French], *Philosophical Transactions*, 90:2 (1800), pp. 403-31.

ID. (1801), "De l'électricité dite galvanique", *Annales de chimie*, 40 an X [1801], pp. 225-56.

ID. (1801a), "Lettre du professeur Volta a J.-C. Delamétherie, sur les phénomènes galvaniques", *Journal de physique, de chimie et d'histoire naturelle*, 53 an X [1801], pp. 309-16.

ID. (1805), *L'identitá del fluido elettrico col cosi detto fluido galvanico vittoriosamente dimostrata con nuove esperienze ed osservazioni* [1805]. *Memoria comunicata al signore Pietro Configliachi, professore di fisica sperimentale nell'Università di Pavia e da lui pubblicata con alcune note*, Pavia: G. Giovanni Capelli, 1814.

ZANTEDESCHI, FRANCESCO (1839), *Saggi dell'elettro-magnetico e magneto-elettrico*, Venezia: Tipografia Armena di S. Lazzaro, 1839.

ID. (1840), *Relazione storico-critica-sperimentale sull'elettromagnetismo*, Venezia: Tipografia del Gondoliere, 1840.